Effect of structural stability on soil erosion by water under conventional and conservation soil management systems in a Sevilla olive plantation area in Southern Spain

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Abstract
Purpose of the study was the investigation of soil losses and runoff on microplots comparing 3 different soil types (Aridic Calcisol, Ferri Stagnic Luvisol and Chromic Calcaric Cambisol) under conventional and conservation soil management. Experimental data were obtained from a set of 12 soil erosion microplots (invested in the framework of EU project INCO-COPERNIKUS-IC15-CT98-0106). Eroding soil material from the main wheel track of Aridic Calcisol was sampled in a collectorbox. Superficial unsaturated hydraulic conductivity was investigated at all sites. Soil physical examination took place at Ferri Stagnic Luvisol and Chromic Calcaric Cambisol.
Conservation tilled plots show due to vegetation effect lower soil losses compared to conventional tilled sites, in 50% higher runoff and lowest hydraulic conductivity at large. Both last-mentioned effects are caused by the platy soil surface and subsurface structure. Among conventional tilled sites lowest runoff and soil losses were measured in the Ferri Stagnic Luvisol based on high top soil sand content and thus very high hydraulic conductivity. Aridic Calcisol and Chromic Calcaric Cambisol show alternating highest soil losses, whose great silt and clay content enhances the development of hydrophobic surface structures and diminishes the hydraulic conductivity. Collectorbox soil losses in the main wheel track exceed those of the microplots for a multiple. Alike do erosion losses presented in literature exceed measured data. Both effects are due to the short slope length of microplots. In conclusion conservation soil management is effective in reducing soil erosion losses in comparison to conventional soil management. High contents of sand decrease runoff and soil losses. Platy structure develops under conservation soil management and minimizes the hydraulic conductivity resulting in high runoff. Reduced hydraulic conductivity and so high runoff in conventional tilled Aridic Calcisol and Chromic Calcaric Cambisol is caused by surface hydrophobicity due to high silt and clay content.

Keywords: soil water erosion; unsaturated hydraulic conductivity; structural stability; conventional tillage; conservation tillage, soil protection

1 Introduction
Soil water erosion is a huge problem in olive groves accumulating to an annual total soil loss of 60 up to 105 t ha^{-1} (Rodero Pérez et al., 2000). Aggressiveness of the Mediterranean climate by means of alternating periods of drought and precipitation of high intensity within short time periods, cultivation on steep slopes, intensive tillage treatments, surface sealing and sparse vegetation cover enhance the loss of soil material and nutrients causing a reduction of soil productivity leading to degradation and long term desertification. 75% of the table olives are produced in the region of Sevilla succumb to typical Mediterranean climate. Precipitation maximum takes place during winter whereas the main vegetation period ranging from May to September is characterized by extensive drought and a theoretical precipitation deficit of 360 mm. Therefore it is essential to offer best possible access for the precipitation to the soil by surface enlargement throughout tillage operations and to save soil water resources for agricultural crop growth by eliminating pest plants. On this account conventional soil management is prevalent in olive plantations in southern Spain. Caron et al. (1996) stated that a stable structure, resistant to the stress induced by wetting, is important for maintaining agricultural productivity and reducing erosion.

2 Material and methods

Experimental data were obtained in field experiments from a set of 12 soil erosion microplots (invested in the framework of EU project INCO-COPERNIKUS-IC15-CT98-0106) established in an olive plantation area near Sevilla in southern Spain. Climate conditions are Mediterranean, with an average annual temperature of approximately 18°C and mean annual rainfall of about 500 mm very irregularly distributed throughout the year. According to WRB (1998) three different soil types (Aridic Calcisol, Ferri Stagnic Luvisol and Chromic Calcaric Cambisol) under two different management systems (conventional and conservation) were investigated. Seven soil erosion events were measured from four experimental treatments: S1, S2, S3 and S4. Each plot is sized $8m^2$ (1m width, 8m length) with similar slope: S1 and S2 6%, S3 5% and S4 7%. Eroding soil material from the main wheel track (3m width, 105m length) of S1 was sampled in a collectorbox. The combination of experimental microplot identifier, soil type, management system and depth-specific properties is described in Tab. 1.

Tab. 1: Plot identification, soil type, management system and depth-specific properties.

microplot	soil type (WRB)	management system	depth (cm)	$CaCO_3$ (%)	Corg. %	texture (%) Sand	Silt	Clay
S1	Aridic Calcisol	conventional	0-16	10	1,0	55	23	21
S2	Aridic Calcisol	conservation	0-15	20	0,7	50	31	17
S3	Ferri Stagnic Luvisol	conventional	0-20	0,5	0,7	72	10	16
S4	Chromic Calcaric Cambisol	conventional	0-15	8,5	1,0	51	25	22

Soil superficial unsaturated hydraulic conductivity was calculated from five infiltration measurements with disc infiltrometer according to Zhang (1997) using five replications.
Four pits nearby the microplots were excavated. Soil profile description in all pits followed WRB (1998), analysis of $CaCO_3$ and Corg. content according to Schlichting et al. (1995). Sampling for physical analysis took place in S3 and S4. The pre-compression stress value as an indicator for soil structural stability (Horn, 2002) was investigated graphically according to Casagrande (1936) and calculational following Baumgartl and Köck (2004).

3 Results

3.1 Microplot soil erosion, runoff and unsaturated hydraulic conductivity

Soil losses and runoff were compared in conventional (S1) and conservation (S2) site of the Aridic Calcisol to analyze the influence of agricultural management systems, and in conventional tilled Aridic Calcisol (S1), Ferri Stagnic Luvisol (S3) and Chromic Calcaric Cambisol (S4) to calculate the effect of soil type and characteristics. Lowest values for soil erosion (Fig. 1) at all were measured in S2, but runoff is in 50% higher than in S1. Lowest values of unsaturated hydraulic conductivity (Fig. 2) constantly appear in S2 indicating a low water conductance of pore space. Among conventional tilled sites lowest runoff was consequently measured in S3, going along with highest rates of unsaturated hydraulic conductivity tending to result in low soil losses. S1 and S4 tend to show alternating maximum erosion losses and runoff and lowest unsaturated hydraulic conductivity. Greatest soil losses and runoff are associated with highest rain intensity.

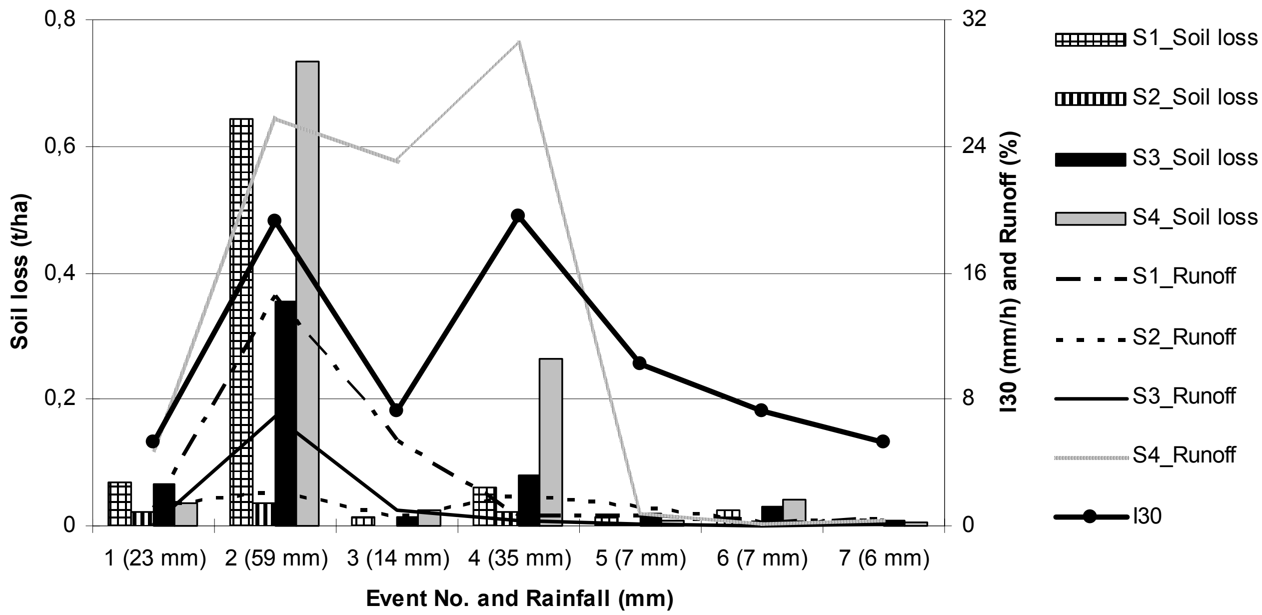

Fig. 1: Mean values of soil loss (t/ha), I_{30} (mm/h) and runoff (%) on microplots.

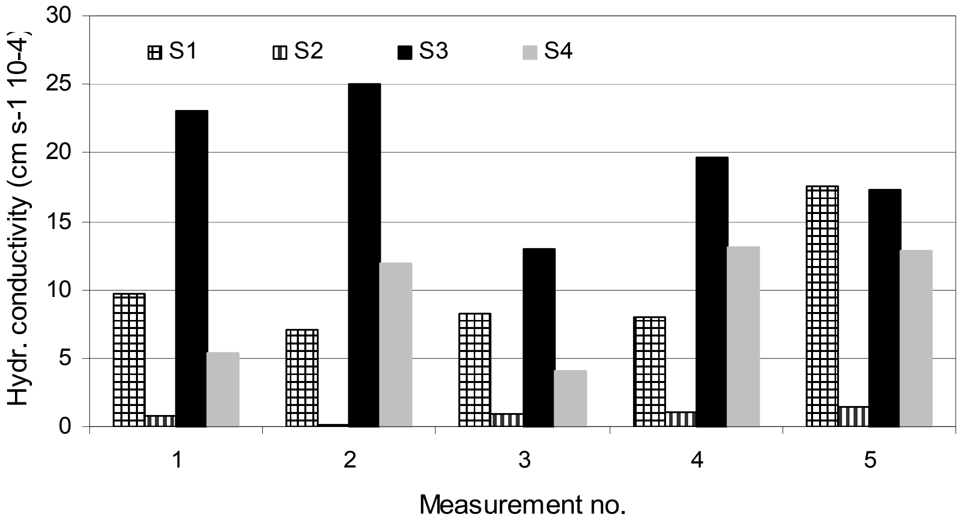

Fig. 2: Unsaturated hydraulic conductivity (cm s^{-1} 10^{-4}) of the soil surface.

3.2 Collectorbox soil erosion on main wheeling track

Soil loss on the main wheeling track of the Aridic Calcisol (Fig. 3) was measured four times. Highest soil loss was measured during an I_{30} of 19 mm h^{-1} and 59 mm rainfall to amount to 2,8 t/ha per erosion event. Similar intensity (I_{30} of 20 mm h^{-1}) but lower quantity (42 mm) results in minor soil loss (1,8 t/ha).

Fig. 3: Collectorbox in the main wheel track of S1 (Aridic Calcisol).

3.3 Measured soil structural stability

The pre-compression stress value can be interpreted as structure stabilizing indicator towards soil erosion. Soil structural stability (Fig. 4) at water suctions below -150 hPa is medium in S3 (n=8) and low in S4 (n=6) according to DVWK (1995). Both sites are prone to erosion. Increasing water suction leads to higher structural stability. Between -150 and -500 hPa pre-compression stresses reach high and medium values in S3 (n=5) and S4 (n=3). Above -500 hPa structural stability is classified as very high in S3 (n=4) and high in S4 (n=2).

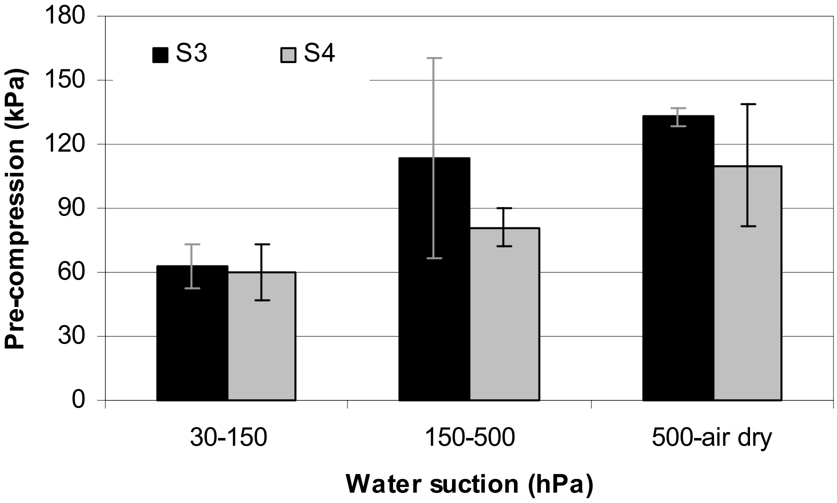

Fig. 4: Pre-compression values (kPa) at determined drainage-classes (hPa).

4 Discussion

4.1 Microplot soil erosion, runoff and unsaturated hydraulic conductivity

Differences in S1 and S2 concerning soil losses, runoff and hydraulic conductivity are due to applied management techniques. With S2 showing lowest erosion losses, vegetation cover is considered to be an effective protection against water erosion. In contrast to literature stating reduced runoff from no tillage sites because of greater number of macropores (Rachmann et al., 2003) S2 shows a platy surface and subsurface structure. The resulting way elongation and time lag of infiltration approved by lowest hydraulic conductivity lead to in 50% higher surface runoff. Superficial tillage loosens the soil and creates cavities (Lampurlanés and Cantero-Matínez, 2006) participating in superficial soil water transport as demonstrated by higher hydraulic conductivity in S1. But at the same time the pulverized relatively loose material is prone to erosion to become apparent as high sediment freight. Lowest runoff and highest infiltration rates among conventional tilled sites in S3 can be explained by shallower slope, high sand and low silt content in comparison to S1 and S4.

Silt and clay are prone to water erosion according to Rodero Pérez et al. (2000) the latter induces hydrophobic surface conditions (Pastor et al., 2001) and causes lower hydraulic conductivity, as shown in S1 and S4. These sites show increasing runoff and higher sediment losses. Taking into consideration all erosion events no plot shows continuous results. The similar structural stability at low water suction ranges between -30 and -150 hPa proofs a similar erosion risk in S3 and S4.

4.2 Collectorbox soil erosion on main wheeling track

Soil losses on the main wheeling track of the Aridic Calcisol are higher than in the adequate micro-plot due to greater slope length. A 50% increase in slope length enhances soil losses for about 30% (Auerswald, 2002).

4.3 Measured soil structural stability

Because of the similar low tending to medium pre-compression stress values the erosion risk in S3 and S4 is considered as equal for water suctions between -30 and -150 hPa. Above -150 hPa S4 tends towards lower structural stability and thus underlies an increasing risk of structural damage throughout tillage operations and thereby enhanced risk of water erosion.
The high sand content in S3 going along with a material own higher textural pore space provides great hydraulic conductivity, low runoff and hence in most cases low erosion losses.

5 Conclusion

Results from experimental soil erosion mesurements suggest that conservation management is effective in reducing soil erosion. An unfavourable platy surface and subsurface structure developed under no till conservation management despite intact plant cover leading to diminished unsaturated hydraulic conductivity and therefore increased surface runoff.
High sand contents increase the unsaturated hydraulic conductivity and result in low runoff values as could be seen in the Ferri Stagnic Luvisol (S3). Larger contents of silt and clay as in the Aridic Calcisol (S1) and Chromic Calcaric Cambisol (S4) deplete the hydraulic conductivity resulting in increased soil losses and runoff values. Microplot soil losses are lower than mentioned in literature due to the short slope length of 8m. Soil loss data gained in the collectorbox of main wheeling track exceed those of equal conventional tilled micro-plot for a multiple because of greater slope length. Multiple tractor crossings under moist soil conditions should be avoided, because exceed of pre-compression stress is leading to plastic deformation and structural damage resulting in an increase of soil erosion and power-input for tillage. Little pre-compression stresses accompanied with low water suction indicate a higher risk of particle displacement.

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